HYDROSTATIC GAS SEAL PREDICTIONS

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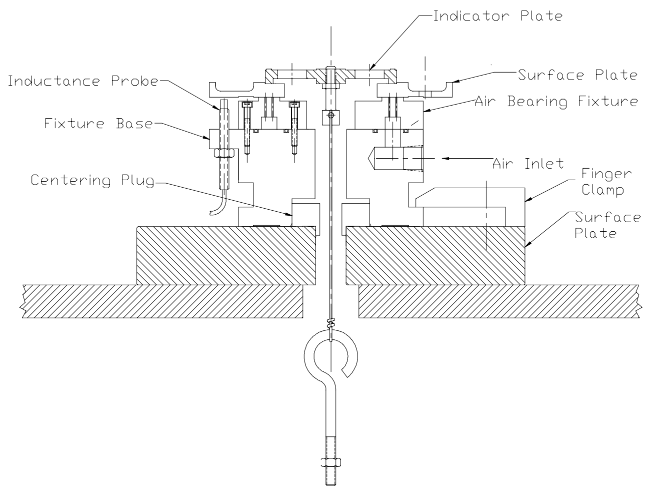
Data Bank

- Stein Seal Company has accumulated voluminous data on hydrostatic configurations
- Objectives were to compare theoretical predictions from code GFACE against test results

Test Rigs

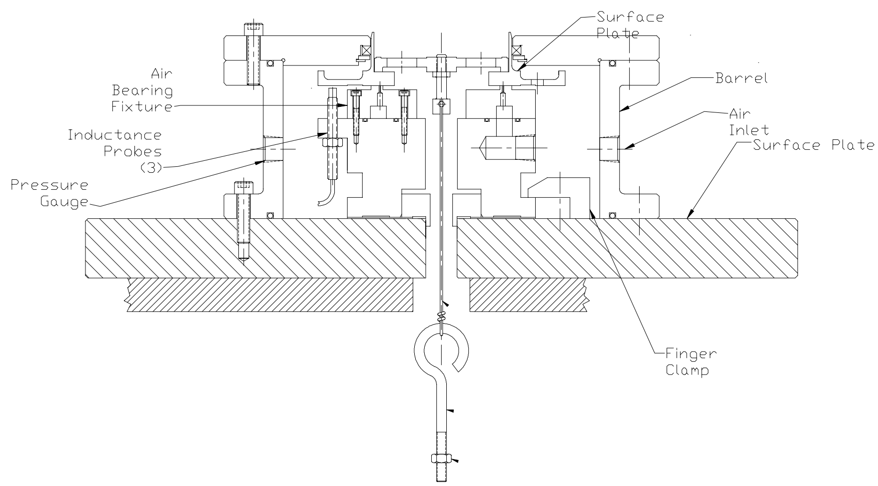
- Rigs with and without pressure barrel
- Principal measurements are clearance and leakage with constant applied load and variable pressure

Stein Static Test Rig



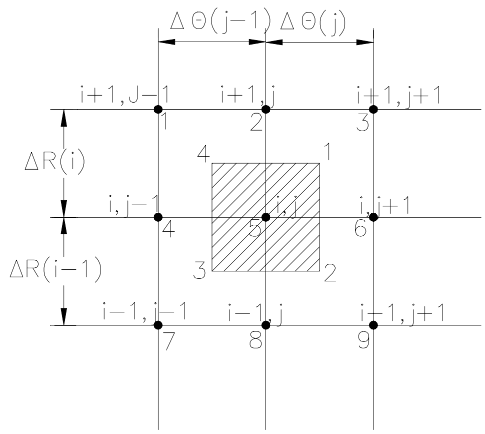
The air bearing fixture containing the hydrostatic configuration is mounted to a base plate. A surface plate loaded by dead weights is mounted atop the air bearing fixture. Pressurized inlet air to the base communicates with the fixture annulus to feed the hydrostatic orifices. Three inductance probes measure liftoff clearance and a flow meter measures inlet flow.

Static Test Rig –Pressurized Environment



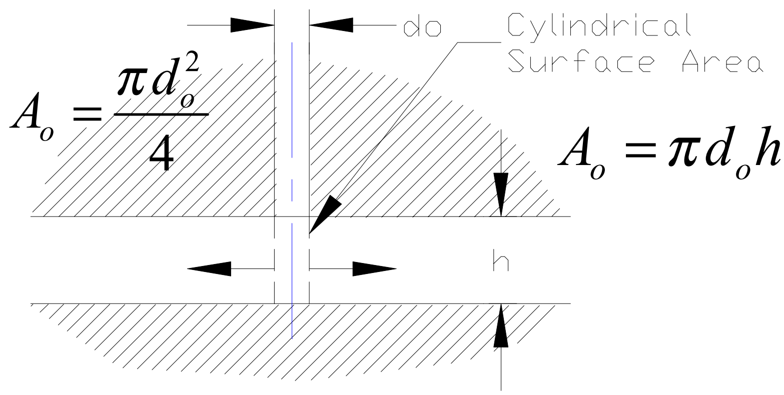
Often the hydrostatic seal is pressurized from the OD and the same pressure is used to feed the hydrostatic orifices. To simulate OD pressurization, a barrel is inserted around the fixture and the barrel is pressurized.

Grid Network



The analytical procedure models the interface with a grid network in the R-θ direction. A variable grid feature allows the spacing to vary in either direction. Surrounding each grid point a cell is inserted whose perimeter is bounded by half the distance to the adjacent grid point. The analytical procedure conducts a mass flow balance through the cell.

Source Point



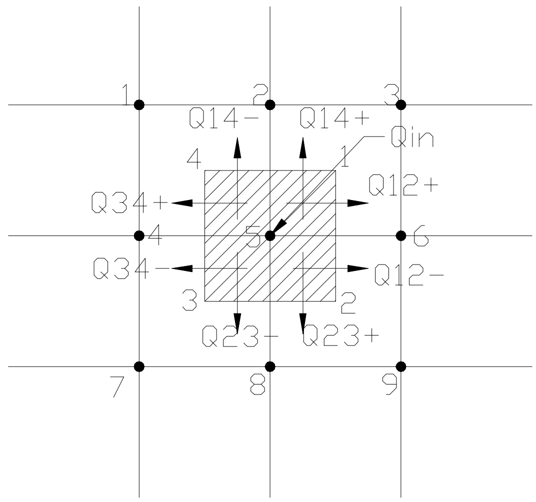
The variable grid identifies the locations of all the source points. At a source point the inlet flow traverses two orifices in series. The first orifice restriction is the hole itself and the second is the cylindrical surface area in the film. Note that the cylindrical surface area is clearance dependent. Generally, the cylindrical surface area is the major restriction.

Source Point

- Two orifices in series –hole and cylinder
- Cylinder modeled by variable grid and making rectangular periphery equal to

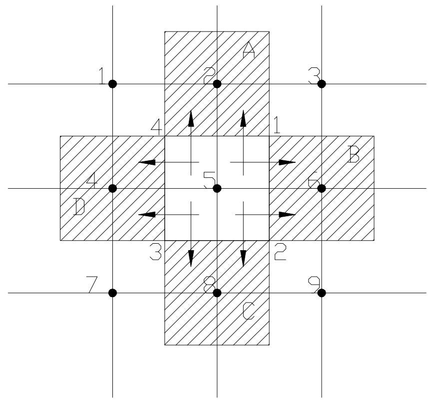
$$\pi d_o$$

Mass Flow Balance at Source



The solution process requires a mass balance at each grid point. At a source point the balance includes inlet flow from the hole and outflow around the periphery. The periphery is made equal to the circumference of the cylinder by implementing the variable grid properties of the code. The flow into and out of the source cell utilizes the orifice equations.

Cell Neighbors



The code incorporate provisions to assure that flow into the cells surrounding the source point equals the corresponding outflow from the source cell.

Flow Equations

- Laminar

$$Q = -\frac{PH^3}{R}\frac{\partial P}{\partial \theta}\frac{\Delta R}{2} + \Lambda RPH\frac{\Delta R}{2}$$

- Orifice

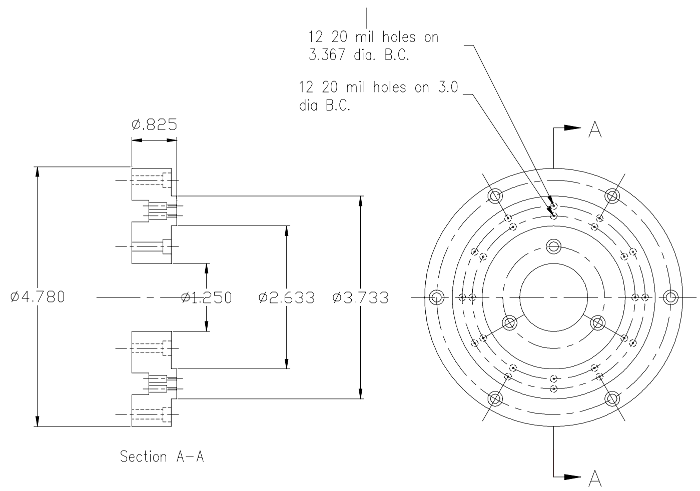
$$Q = (OFC)(A_o)P_s\left\{\left(\frac{P_r}{P_s}\right)^{\frac{2}{\gamma}}\left[1-\left(\frac{P_r}{P_s}\right)^{\frac{\gamma-1}{\gamma}}\right]\right\}^{\frac{1}{2}}$$

$$if\ \frac{P_r}{P_s} \le P_{cr}\ then\ \frac{P_r}{P_s} = P_{cr}$$

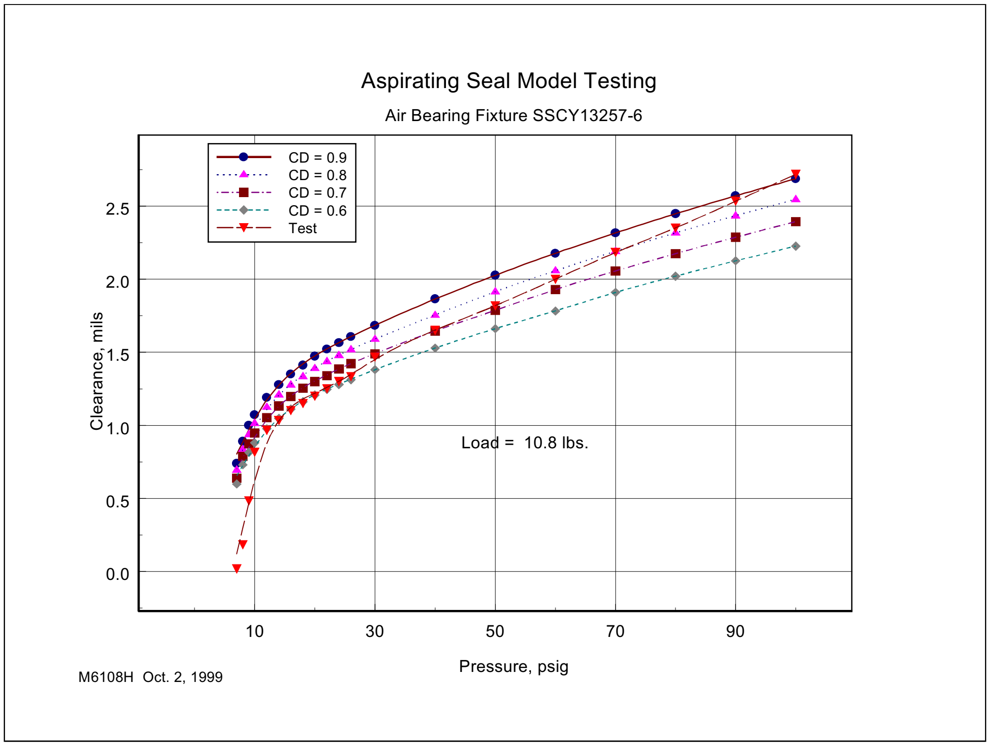
$$where\ P_{cr} = \left(\frac{2}{\gamma+1}\right)^{\frac{\gamma}{\gamma-1}}$$

The principal flow equation throughout the grid is the laminar flow equations emanating from the Reynolds equation. Exceptions at at source points and inertia lines where the orifice equations are applied.

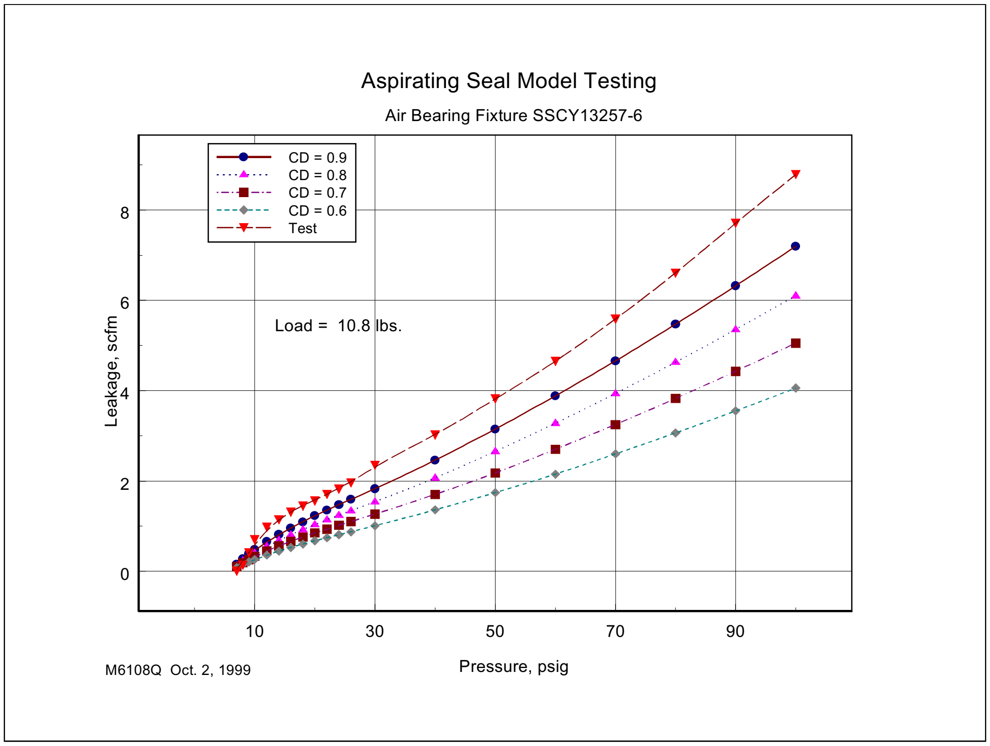
Hydrostatic Configuration



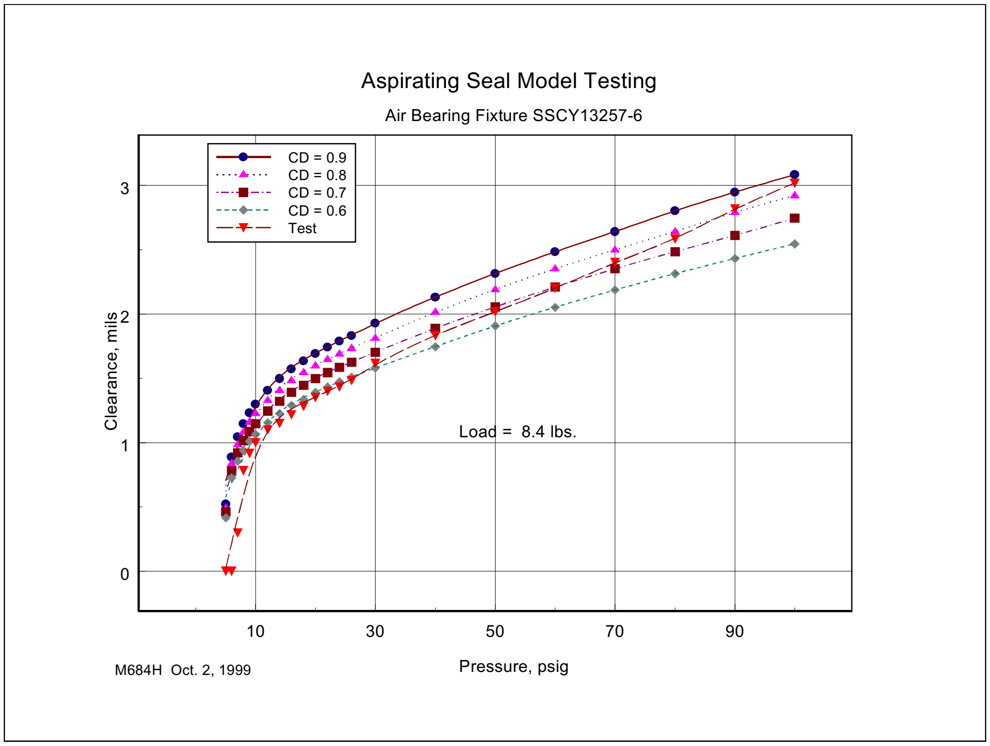
One of the configurations tested and analyzed is shown on slide12. It consists of a double row of aligned orifices. Each row has 12 holes of 20 mil diameter. One row is on a 3.367 B.C. and the other on a 3.0 inch B.C. The OD of the hydrostatic interface is 3.733 in and the ID is 2.633 in.



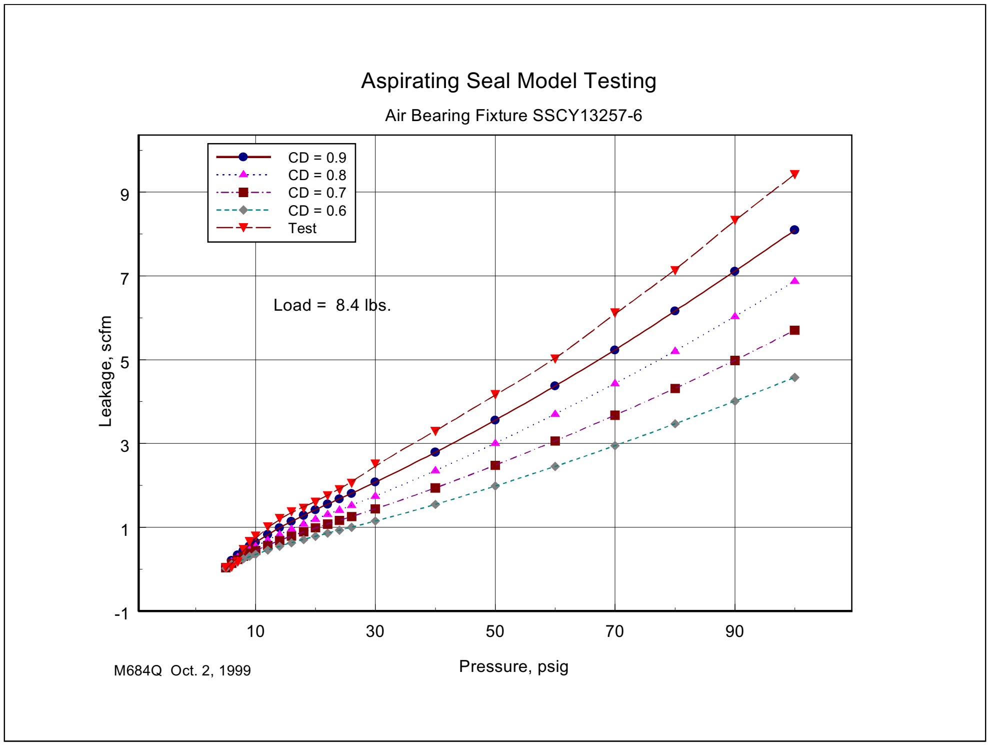
A load of 10.8 lbs was applied to the test rig with the hydrostatic configuration of slide 12 in place. The test procedure was to vary the supply pressure and measure clearance and leakage. Test results are indicated by the inverted solid triangle. Superimposed are theoretical results with variations in the Coefficient of Discharge.



Flow results are indicated on this slide. Note that the test results indicate slightly higher values than the theoretical results which was consistent for all applied loads.



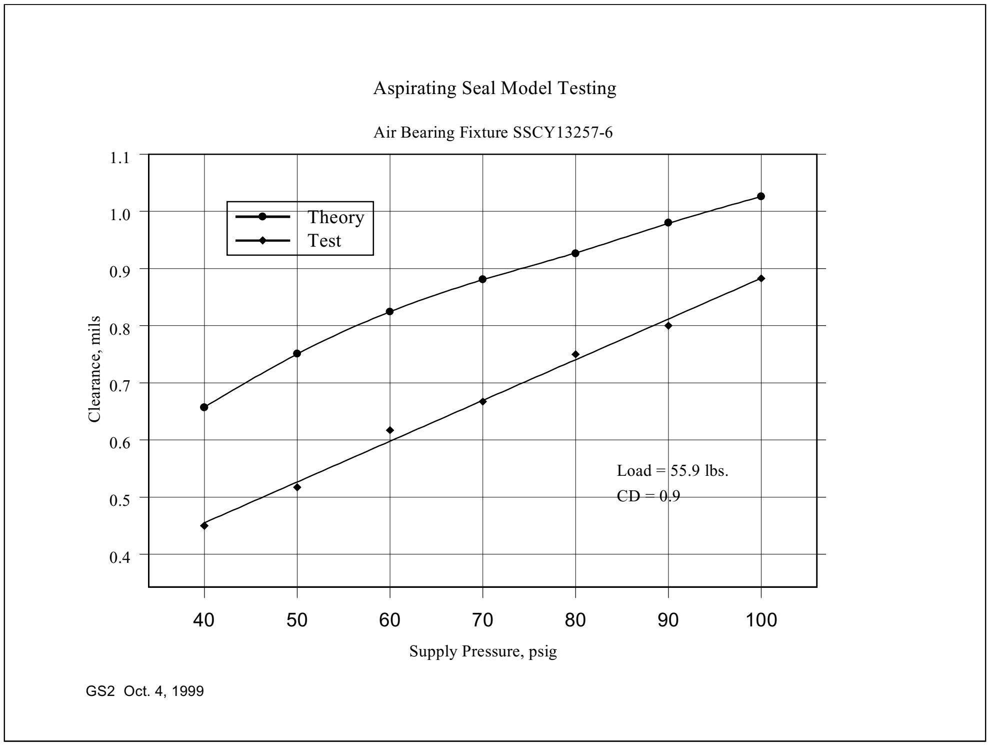
Similar results are indicated for a different applied load. Note that a Cd of 0.9 produces slightly higher clearances. However leakage results for Cd of 0.9 show slightly lower values.



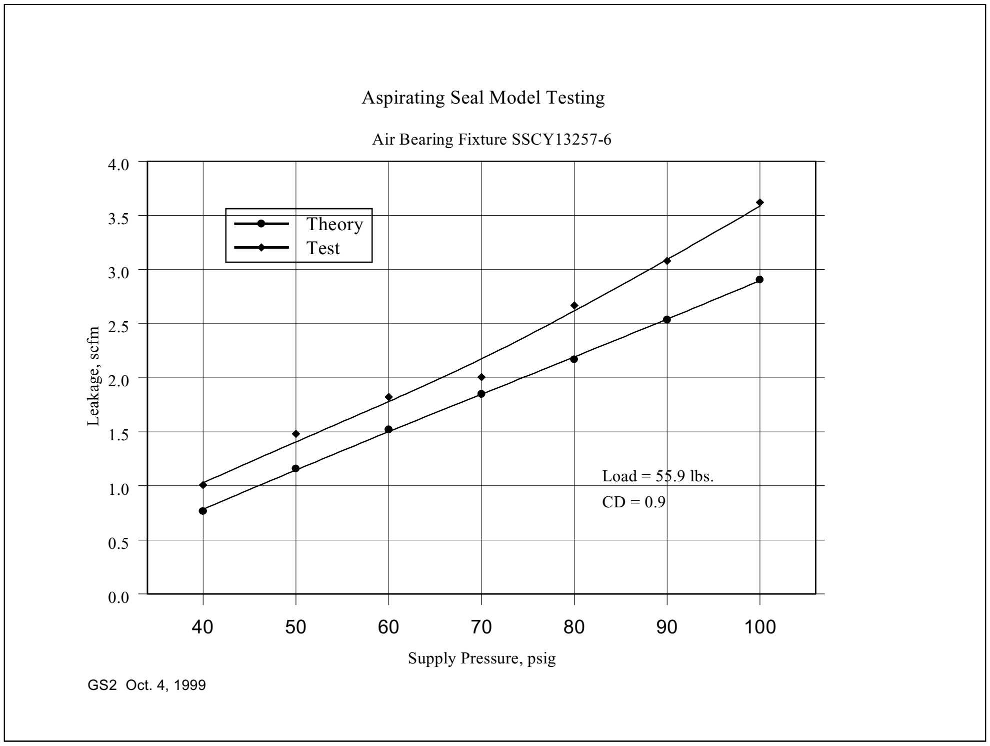
Leakage results at a Cd of 0.9 are slightly lower than test results.

Conclusions

- Theoretical leakage is lower
- Best compromise is Cd = 0.9
- Provides slightly higher clearance and slightly lower leakage

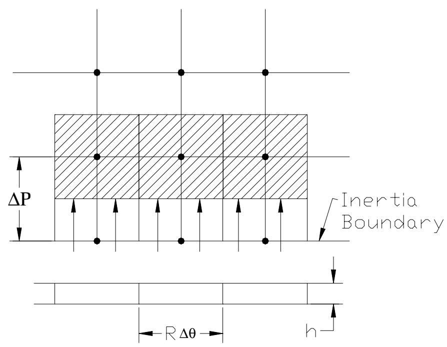


Results for a Cd of 0.9 at a high load are indicated on this Figure.



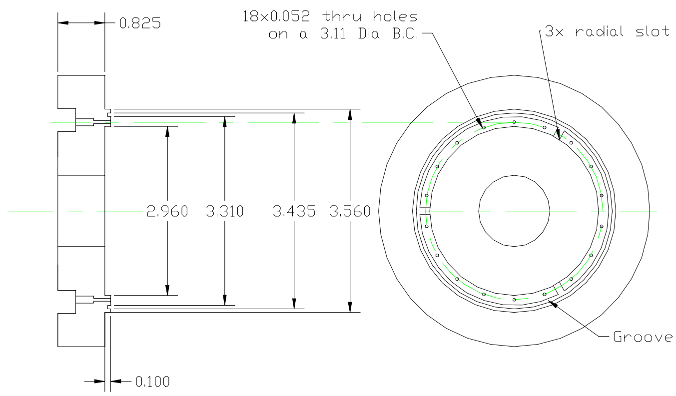
Leakage results are indicated here.

Inertia Boundary

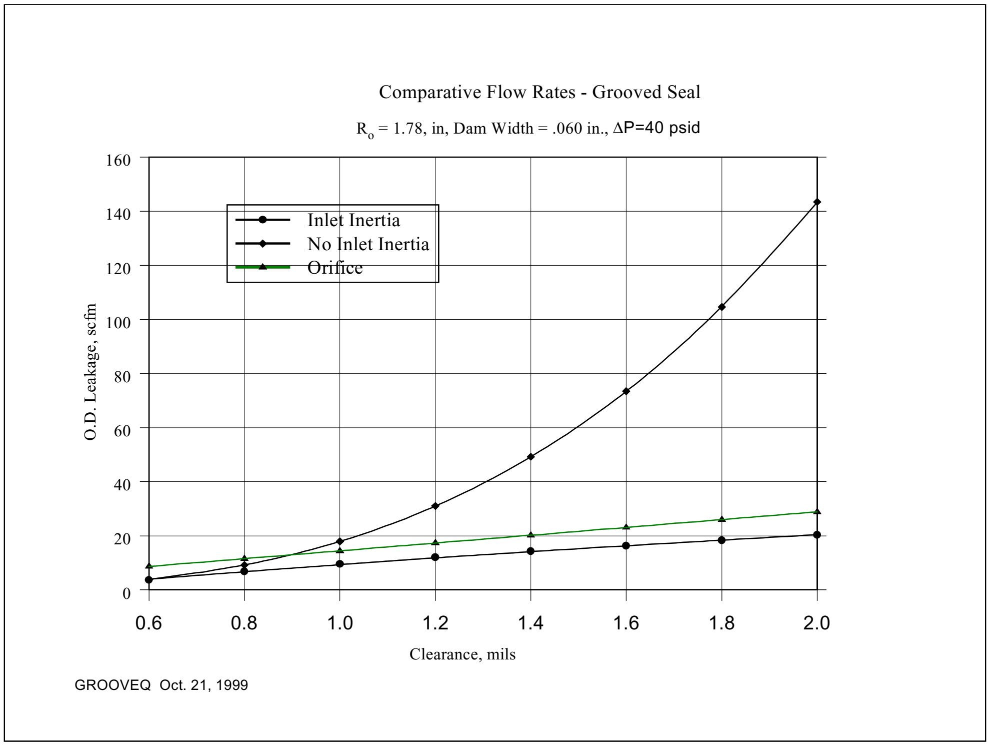


At an inertia boundary The flow into the interior cell is evaluated two ways. The first uses the conventional laminar equations and the second employs the orifice equation. The least of the two flows is selected since it represents the major restriction. Inertia boundaries are important as the clearance grows because laminar flow theory is proportional to the cube of the clearance and result in grossly exaggerated flows.

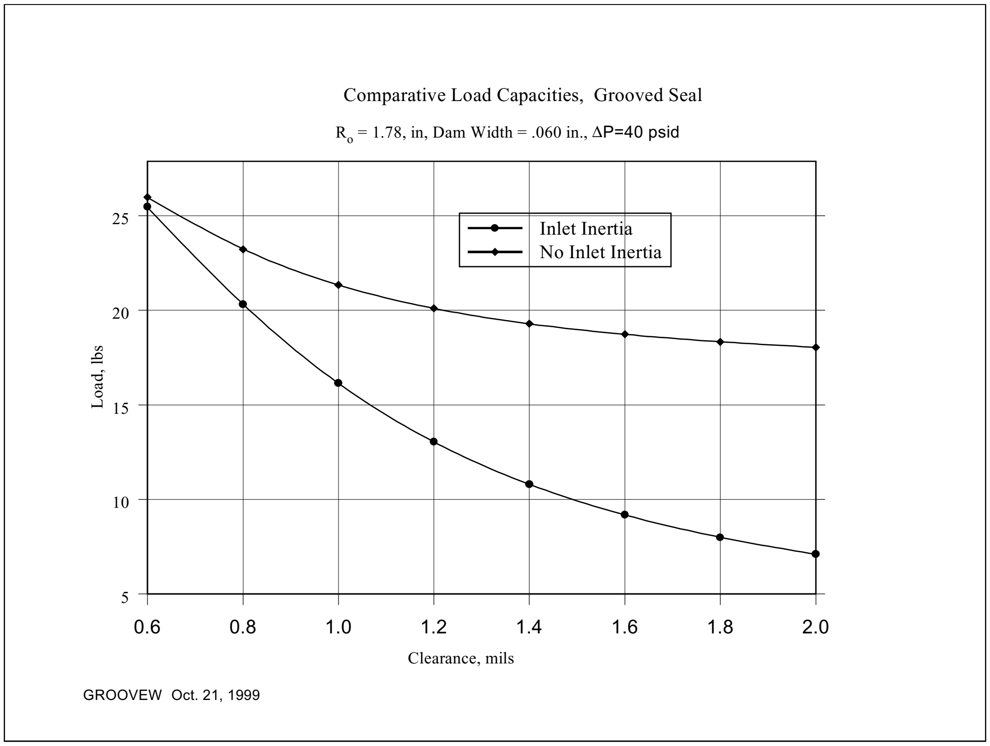
Seal Configuration with Boundary Pressure



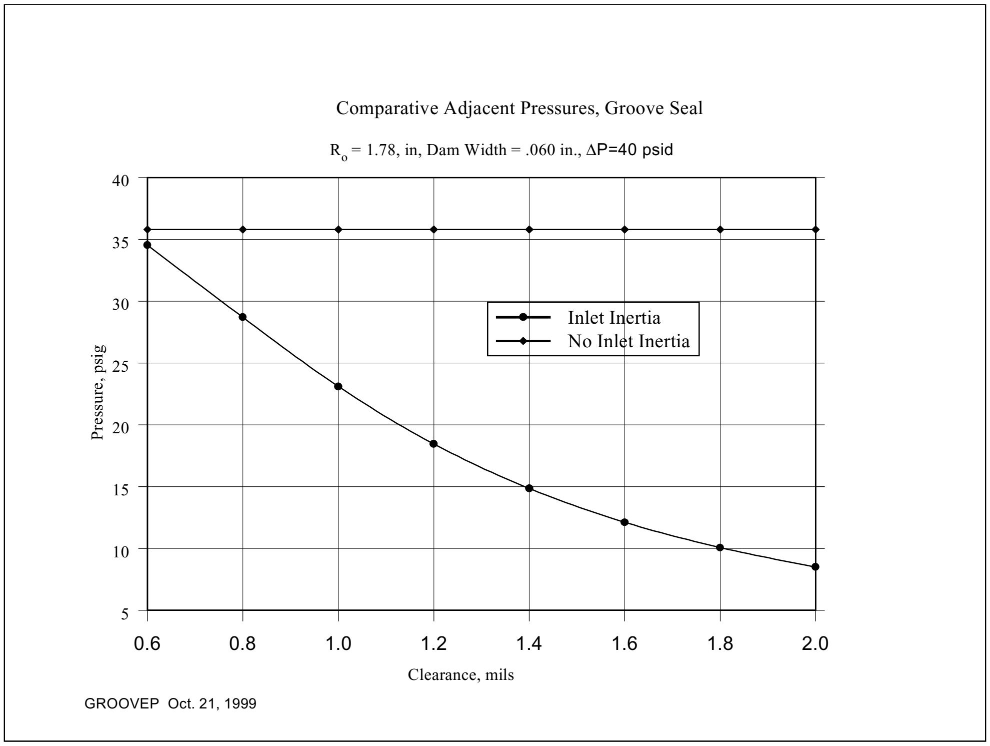
This slide indicates another configuration that will shortly undergo static testing. A deep groove is machined in the hydrostatic interface that communicates with radial slots that exhaust to the ID. High pressure is applied at the OD and also feeds the orifices. The ID is at ambient pressure of 14.7 psia. The groove pressure equals ambient because of the radial slot communication. The concept was designed to surround the hydrostatic region with ambient pressure to improve hydrostatic stiffness and righting moment capacity. The seal dam, which is the region above the groove, is quite narrow as is the entire interface. The leakage across the dam must include inertia effects because of the small aspect ratio.



Theoretical leakage across the seal dam, of the previous configuration, as a function of clearance is shown on this slide. Laminar theory applies to the upper curve. For low clearances of 0.8 to 0.9 mils, laminar theory provides the major restriction because it is lower than the inertia flow and would govern. For subsequent clearance increase, inertia or orifice flow governs as indicated by the lower curve. Note the significant difference in flow between the two theories. Also indicated on the plot is flow as a sharp edged orifice with a full pressure drop of 40 psid. This curve is the choked flow condition and represents the maximum flow that could occur across the seal land for a constant clearance condition.



It is important to accurately establish the opening load capacity of the seal so a proper balance ratio can be designed. There is a significant reduction in load capacity between laminar and inertia theory at the higher clearances. This occurs because of the immediate pressure reduction of inertia theory as indicated on the following slide.



With inlet inertia applied there is a significant pressure reduction immediately adjacent to the boundary which effects all subsequent downstream pressures and results in reduced load capacity. For laminar theory there is hardly any change in the immediate downstream pressure as the clearance increases. Primary pressure reductions occur further downstream.

Conclusions

- GFACE modifications include series orifices at source point and inlet inertia effects.
- Modified code predicts performance of hydrostatic seal reasonably well
- Inlet inertia important for low aspect ratio seals

Conclusions (cont'd)

- Low aspect ratio hydrostatic seals with OD pressure can be prone to moment unbalance instability

Some problems have been experienced with low aspect ratio hydrostatic seals. Righting moments can be insufficient to prevent overturning of the seal. Moment unbalance instability can be of serious consequence in low aspect ratio film seals. Inclined film distributions can result in excessive flow, increased load capacity, and possible contact.